CHAPTER 4

PROCESS SELECTION

4-1. General process selection. In selecting a potable water production system, it is important to estimate costs of various options. The conventional unit of comparison is cost in dollars per 1,000 gallons of product water. Water quality and energy sources will be estimated from simple site reconnaissance. For example, a sea coast site where the water source temperature exceeds 95 degrees Fahrenheit indicates a high-salinity high-temperature combination favoring distillation/condensation processes. Reverse osmosis requires a feed water temperature below 95 degrees Fahrenheit. If local well testing indicates salinity between 500 and 3,000 milligrams per liter and electricity is inexpensive, electrodialysis reversal or highflux reverse osmosis is indicated.

a. Desalination requirements. The design of a desalination system requires a clear understanding of the following: the quantity of product water desired; the quality of the desired product; and the quality of the feed water source. This manual addresses the production of potable water containing less than 500 milligrams per liter of total dissolved solids. Laundries, boilers, mess halls, and hospitals may require water purer than 500 milligrams per liter of total dissolved solids. Potable water from the desalination system may be further treated to meet these requirements in accordance with AR 420-46.

b. Saline feed water quantity. The production of potable water from saline water usually requires a significantly larger quantity of saline feed water than the quantity of potable water produced. When desalination is necessary to produce potable water, the process splits the feed water into two streams. One stream is the product water; the other stream is the brine that contains most of the salts originally in the feed water. In waters that need very little desalination, high-rate reverse osmosis may only reject 5 percent of the feed stream as brine. In reverse osmosis of sea water, more than 70 percent of the intake water may be rejected as brine. Multiply the required product quantity by the reciprocal of the product water recovery fraction to find the quantity of saline water that must be processed to yield the desired quantity of product water. In equation, form, it can be expressed as follows:

$$\frac{100\%}{\text{\% recovery of product water}} \times \text{water demand} = \text{saline feed water flow}$$

In some cases, the limited quantity of an available saline water may require a decision to adopt a more expensive desalination process with a higher water recovery rate. However, it may require choosing a different and more saline feed water with a greater availability.

c. Blending of waters. Blending a high concentration stream with a low concentration stream wastes the osmotic pressure energy between the two streams. Therefore, it is best to match the design of the desalination system to the product quality desired. When a desalination process cannot be economically matched to the desired product quality, then a process that yields water with a very low dissolved material content must be used. To conserve capital and equipment costs and meet the desired water demand, the high purity product water can be blended with the pretreated saline feed water to produce the required product quantity and quality. The following equation can be used to calculate the concentration of a blended water stream:

$$\left(\sum_{i=1}^{i=n} \text{concentration } i \times \text{flow } i\right)/\text{total flow} = \text{blended concentration}$$

When only two streams are blended, the equation can be rearranged to show the flow of concentrated water that when blended with a dilute flow will result in the desired product concentration. This rearranged equation is as follows:

$$\frac{(P - H)(D)}{C - P} = F$$

Where:

P = Desired product water concentration
H = High purity water concentration
D = Flow of the high purity water
C = Concentration in the impure concentrated stream
F = Flow rate of the concentrated stream

Reblending for remineralization is discussed in Chapter 9. The same blend equations will apply to blending for remineralization, which is a more common procedure. See Appendix A for sample problems.

4-2. Process limitations. The various desalination processes presently available have limitations that must be considered prior to selecting a desalination process for a particular site. These limitations apply only to the desalination processes themselves; pretreatment can be and is often used to bring a saline feed water within limits so that a desalination process can be used. The raw feed water chemistry for all desalination systems must be evaluated thoroughly for constituents that may precipitate in the desalination system.

a. High-temperature distillation. High-temperature distillation is limited by the saturation of alkaline earth metal salts, such as $CaSO_4$, $BaSO_4$, $SrSO_4$, $CaCO_3$, $BaCO_3$, and $SrCO_3$. Carbonate salt scaling can be controlled by acid addition. The recovery of water from a hightemperature distillation plant is usually limited by calcium sulfate solubility. When the concentration of the sulfate and the limiting alkaline earth metal is one-third of the saturated condition at ambient temperature, distillation design must include pretreatment to reduce or inhibit the scaling ions. High-temperature distillation is also limited to oil and grease levels below 1 milligram per liter. All other limitations on the high-temperature distillation process are equipment specific and require individual evaluation.

b. Low-temperature and mechanical distillation. Low-temperature and mechanical distillation systems are limited to operation below saturation of alkaline earth sulfates and carbonates. The lower operating temperature permits economical operation on waters that are at or below half saturation at ambient temperature. Oil and grease are limited to less than 1 milligram per liter. Any other limitations are equipment specific.

c. Reverse osmosis. The most severe limitation on reverse osmosis is the maximum limit of 50,000 milligrams per liter of total dissolved solids in the feed water. Another limitation is that there must be no iron in the feed water. This limitation is so rigid that only stainless steel and nonferric materials will be used downstream of the iron removal. The solubility of alkaline earth sulfates and carbonates limits reverse osmosis treatment. Any water containing less than 4,000 milligrams per liter of total dissolved solids that would be saturated with an alkaline earth sulfate when the concentration is multiplied by 1.5 should not be considered for reverse osmosis desalination. Reverse osmosis is limited to waters that do not have silica saturation in the reject brine. Silica chemistry is extremely complex. When the molybdenum reactive silica concentration exceeds 30 milligrams per liter as SiO2 or the pH exceeds 8.3 in the brine stream, an environmental chemist or engineer should be consulted. Reverse osmosis is also limited to the treatment of waters with less than 1 milligram per liter of oil and grease.

(1) Cellulose acetate membranes. Cellulose acetate membranes are usually limited to pH levels between 4.0 and 7.5. Cellulose acetate membranes require some form of continuous disinfection with the feed water to prevent microbial degradation of the membranes and can tolerate up to 1 milligram per liter of free chlorine. Therefore, cellulose acetate membranes are usually disinfected by maintaining 0.2 to 0.9 milligrams per liter of free chlorine in the feed water. Cellulose acetate membranes cannot be used on waters where the temperature exceeds 88 degrees Fahrenheit. Cellulose acetate membranes should not be used at pressures greater than the manufacturer's recommended pressure, since they are prone to membrane degradation by pressure compaction.

(2) Polyaromatic amide membranes. Brackish water polyaromatic amide membranes are generally limited to operation in feed waters between pH 4 and pH 11. Polyaromatic amide membranes are less pH tolerant and should not be used outside of the range pH 5 to pH 9. All polyaromatic amide membranes are limited to use on feed streams that are free of residual chlorine. If chlorination is necessary or desirable as a pretreatment option, complete dechlorination must be effected. Polyaromatic amide membranes are tolerant of water temperatures up to 95 degrees Fahrenheit. While polyaromatic amide membranes are not as quickly or completely compacted as are cellulose acetate membranes, manufacturer's recommended pressures must be followed to prevent mechanical damage to membrane modules.

d. Electrodialysis reversal. While electrodialysis reversal has been used to treat water as saline as sea water, 4,000 milligrams per liter of total dissolved solids is considered to be an upper limit for economical operation. Some electrodialysis membranes can tolerate strong oxidants, like chlorine, but most cannot. The reversal of polarity used in electrodialysis reversal for removal of scale allows operation on water that is saturated with alkaline earth carbonates. Saturation with an alkaline sulfate with low carbonate alkalinity should be avoided.

4-3. Distillation/condensation energy. In distillation/condensation plants, energy is used in the form of steam and elec tricity. Steam is used to heat the saline water to increase its vapor pressure. Normally, electricity is used to run the compressor in vaporcompression distillation. If excess steam is available, its use as a power source should be

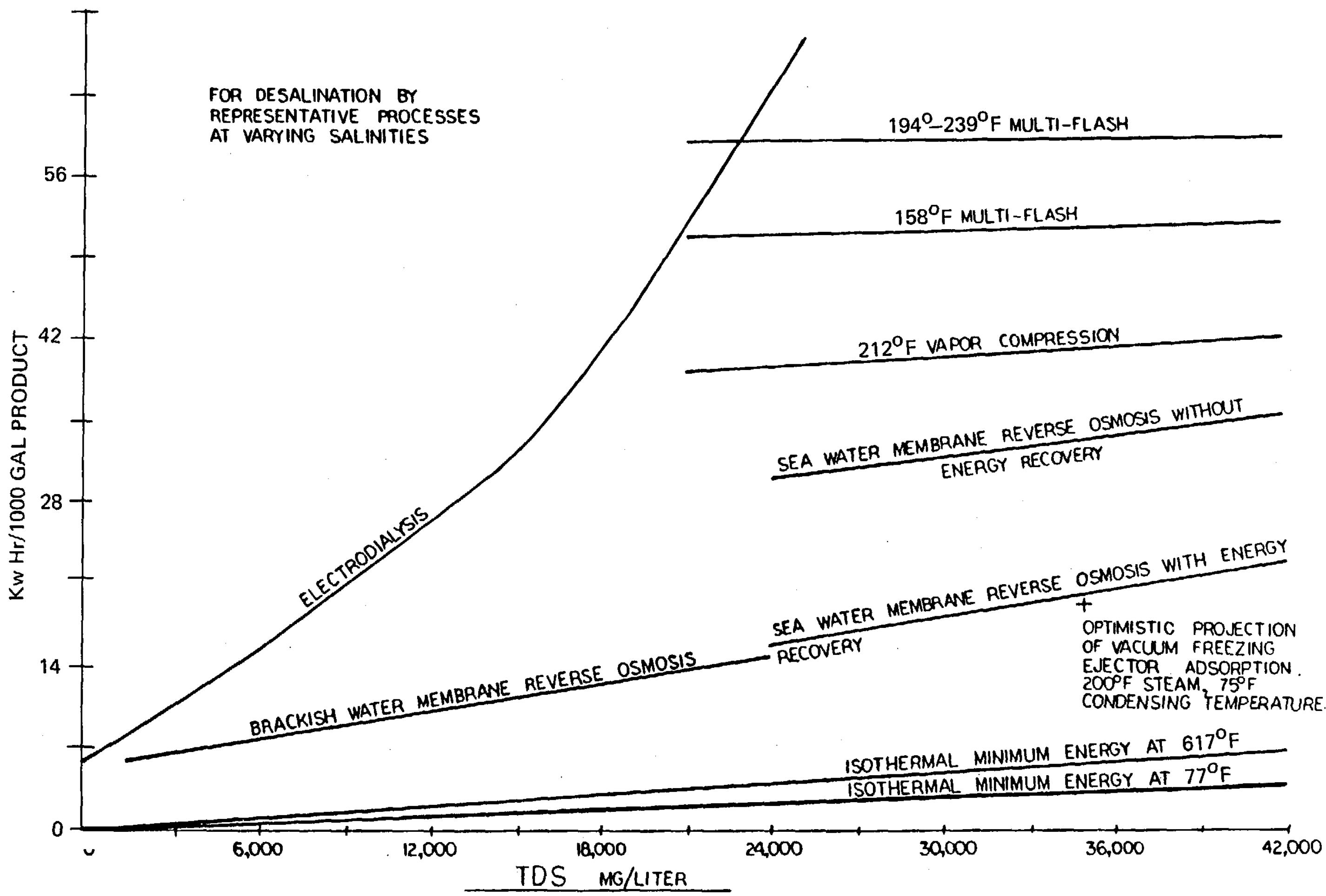

Figure 4-1. Energy consumption.

RULE	A If the freshest source of water is:	B And if the desired output water will be:	C And if electricity is to be generated:	D And if the projected cost ratio of 264°F Steam: Electricity	E Then investigate the cost of:	F And have the following tests performed:
1	More salty than sea water	Potable water			Transportation of fresher water: distillation can be used but at great expense	TDS
2	Sea water	High-pressure boiler feed water	By steam turbine		Distillation followed by ion exchange	TDS, Ca^{++}, $SO_4^{=}$, $CO_3^{=}$, pH refer to water testing requirements in Appendix B
3	Sea water	Potable water	By steam turbine	Greater than $\frac{10 \times 10^6 \text{ BTU}}{1 \text{ kwh}}$	Thermal distillation with or without vapor compression	TDS, Ca^{++}, $SO_4^{=}$, $CO_3^{=}$, pH
4	Sea water	Potable water	By internal combustion engine		Vapor compression distillation and waste heat	TDS, bacterial count, turbidity
5	Sea water	Potable water	No	Less than $\frac{10 \times 10^6 \text{ BTU}}{1 \text{ kwh}}$	Reverse osmosis	TDS, Ca^{++}, $SO_4^{=}$, $CO_3^{=}$, pH, bacterial count, silt density index, turbidity, oil & grease refer to list for reverse osmosis, Appendix B
6	Brackish water	Potable water			Reverse osmosis	TDS, Ca^{++}, $SO_4^{=}$, $CO_3^{=}$, pH, bacterial count, silt density index, turbidity, oil & grease
7	Slightly saline brackish water	Potable water			Electrodialysis reversal	TDS, full ionic breakdown, bacterial count, turbidity refer to list for electrodialysis reversal, Appendix B

Table 4-1. Preliminary desalination process selection.

investigated. The amount of electricity or mechanical work that steam will yield depends on its temperature as well as the temperature to which it can be condensed. The energy consumption of both vapor compression and thermal distillation, as related to the total dissolved solids of feed water, is shown in figure 4-1.

4-4. Membrane energy. Historically, membrane desalination systems use less energy than other systems. Brackish water disalination should be accomplished by membrane separation processes because of the reduced energy requirement. The energy consumption of electrodialysis reversal can be made to follow reduced or variable salinity, while the energy consumption of reverse osmosis is set principally by membrane water flux. Again, the energy consumption of electrodialysis reversal and reverse osmosis as a function of the total dissolved solids content of the feed water is shown in figure 4-1. As membrane materials are developed, energy consumption may be reduced.

4-5. Waste disposal. Waste disposal may influence process selection. Since brine disposal costs can be an important part of process economics, brine disposal alternatives must be explored while water quality analyses are being performed. For further information, refer to Chapter 10 on waste disposal.

4-6. Preliminary process selection. Use preliminary site information to eliminate certain desalination processes. A decision logic table for use with preliminary information is shown in table 4-1. Decisions based upon table 4-1 are to be considered preliminary only. Necessary water quality tests to further support the recommedations made in Column E of table 4-1 are in Column F.

4-7. Process selection. When initial site and raw water source selections have been made, use preliminary water quality information with table 4-1 to assist in a preliminary process selection. As more specific information is obtained from laboratory analyses of water quality, make an initial process selection using the second decision logic table, table 4-2. After a treatability investigation has been completed, select the final desalination process. A final decision logic table, table 4-3, assists in the final process selection. The use of the decision logic table sequence will only provide generalized assistance in process selection; additional economic, engineering, and environmental studies may indicate that methods or combinations of methods must be used.

RULE	A	B	C	D	E	F
	If the feed water TDS is (mg/liter):	And if the raw feed water suspended solids are:	And if the product of the $[Ca^{++}][SO_4^{=}]$ moles²/liter² is in the reject brine (see sample problem A-3)	And if the oil and grease in the raw feed water is:	*Then investigate* the cost of:	And have the following pretreatment processes investigated for effectiveness:
1	Greater than 50,000				Transportion of fresher water; distillation of this water is extremely expensive	Precipitation of less soluble salts
2	Between 20,000 - 50,000	Over 20 NTU	Considerably less than 2×10^{-4}	Greater than 10 mg/liter	Reverse osmosis or distillation and steam and electricity	Alum jar tests, pH adjustment 10-micron or smaller filter plugging
3	Between 20,000 - 50,000	Over 1 NTU		Less than 10 mg/liter	Reverse osmosis	Alum jar tests 10-micron or smaller filter plugging UV sterilization
4	Between 20,000 - 50,000	Less than 1 NTU SDI greater than 3		Less than 10 mg/liter	Spiral-wound membrane reverse osmosis	pH adjustment, UV sterilization, chlorine disinfection, chlorine residual
5	Between 20,000 - 50,000	SDI under 3		Less than 10 mg/liter	*Hollow fine-fiber* membrane reverse osmosis	10-micron or smaller filter test, UV sterilization
6	Between 3,000 - 20,000	Over 1,000 mg/liter	Considerably less than 2×10^{-4}	Greater than 10 mg/liter	Distillation	pH adjustment, alum jar test
7	Between 3,000 - 20,000			Less than 10 mg/liter	Reverse osmosis	pH adjustment, alum jar test, silt density index, UV sterilization
8	Between 500 - 4,000				Electrodialysis *reversal*	pH adjustment, alum jar test, *10-micron filter plugging,* chlorine disinfection

Table 4-2. Selecting desalination processes after water quality data are obtained.

RULE	A	B	C	D	E	F	G
	If the treated feed water salinity (mg/l) will be (see note):	And the cost ratio of 264°F steam / 1 kwh electricity will be:	Alkaline earths on the raw water are such that (see sample problem A-3):	And the treated suspended solids are:	And the designated chlorine residual is:	Then investigate the cost of:	With the following pre- and post-treatment technique costs:
1	Between 20,000 - 50,000		Within 66% of saturation	Less than 1 NTU but SDI greater than 3	0.0 mg/liter	Spiral-wound membrane reverse osmosis	Whatever treatment is necessary to produce D and E
2	Between 20,000 - 50,000 Sea Water		Within 66% of saturation	SDI less than 3	0.0 mg/liter	Hollow fine-fiber membrane reverse osmosis	Whatever treatment is necessary to produce D and E
3	Between 20,000 - 50,000		SAMPLE	Less than 1 NTU	Between 1.0 and 0.0 mg/l	Chlorine-resistant membrane reverse osmosis	Whatever treatment is necessary to produce D and E
4	Between 20,000 - 50,000	Greater than 10×10^6 BTU / 1 kwh	Within 50% of saturation	Greater than 1 NTU	More than 1 mg/l	Some form of distillation under 185°F	Anti-scalent
5	Between 20,000 - 50,000	Greater than 10×10^6 BTU / 1 kwh		Greater than 1 NTU	More than 1 mg/l	Some form of distillation	Acid feed (hydrochloric is best)
6	Between 20,000 - 50,000	Greater than 10×10^6 BTU / 1 kwh	$[Ca^{++}]$ multiplied by $[SO_4^{=}]$ Well Under 2×10^{-6}	Greater than 1 NTU	More than 1 mg/l	Some form of distillation	No pretreatment for calcium sulfate scale control
7	Between 3,000 - 20,000			Less than 1 NTU but SDI greater than 3	Less than 1.0 mg/l**	Brackish water spiral-wound membrane reverse osmosis	Whatever treatment is necessary to produce D and E
8	Between 3,000 - 20,000			SDI less than 3	Less than 1.0 mg/l**	Brackish water hollow fine-fiber membrane reverse osmosis	Whatever treatment is necessary to produce D and E
9	Between 500 - 4,000 and especially when expected to vary by more than 15%			Will not plug 10-micron filter	0.0 mg/l**	Electrodialysis reversal	Turbidity removal To 1 NTU and disinfection to less than 1/100 ml.
10	Is stable at some value between 500 - 1000			SDI less than 3	Less than 1.0 mg/l**	Low pressure/high flux membrane reverse osmosis	Whatever treatment is necessary to produce D and E

Table 4-3. Final selection of a desalination technique from treatability data.